World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:6, No:10, 2012

Design Methodology through Risk Assessment of Massive Water Retaining Structures

A. Rouili

***Abstract*—**In the present paper the results of a numerical study are presented, numerical models were developed to simulate the behaviour of vertical massive dikes. The proposed models were developed according to the geometry, boundary conditions, loading conditions and initial conditions of a physical model taken as reference. The results obtained were compared to the experimental data. As far as the overall behaviour, the displacements and the failure mechanisms of the dikes is concerned, the numerical results were in good agreement with the experimental results, which clearly indicates a good quality of numerical modelling. The validated numerical models were used in a parametric study were the displacements and failure mechanisms were fully investigated. Out of the results obtained, some conclusions and recommendations related to the design of massive dikes are proposed.

***Keywords*—**Water conservation, dikes, risk assessment and numerical modelling.

I. Introduction

OVER the years, rising populations, growing industrialization, and expanding agriculture in developing countries increased the demand for water production and conservation techniques. Water conservation has become a strategic issue, and important effort is continuously made by most countries in order to collect and conserve water, by building dikes, dams and reservoirs. Designing, building and maintenance of these structures is actually a challenging work for civil engineers, as unjustified large safety factors are still induced to ensure their safety. However, the related literature shows that: a unified design methodology of the different types of massive water retaining structures could only be achieved through assessment of the risk related to their individual behaviour under hydraulic loads and their failure mechanism. In the present paper the results of a numerical study are presented, numerical models were developed in two and three dimensions, to simulate the behaviour of vertical massive dikes (water-blocking) walls, which will from above look like a standard dike, but is in fact hollow and can accommodate structures the seaside. The proposed models were developed according to the geometry, boundary conditions, loading conditions and initial conditions of the physical model taken as reference. The later, was developed and tested in full scale by previous researchers [1]. The validated numerical models were used in a parametric study were the displacements and failure mechanisms were fully investigated. Out of the results obtained, some conclusions and recommendations related to the design of massive dikes are proposed.

A. Rouili is with the University of Tebessa, Algeria. Route de Constantine, 12002, Tebessa, Algeria ; (e-mail : arouili@hotmail.com).

II. Experimental Results For Validation

In this exercise reference is made to a comprehensive experimental work realized in the laboratory of soil mechanics of Delft by Heins and Leeuw, [1], experimental investigation was carried out within the framework of the future construction of a 5 km dike called the project Delta. The reference model is made of a massive rigid bloc of 15 m on 27.7 m of base and 10 m high, with an overall weight of 1785 tons. The bloc was placed in 7 m of water. The foundation of the block was instrumented by displacement transducers. The pressure of contact at the ground level was about 33 KN / m2. The horizontal effort was applied by six hydraulic jacks. The applied inclined forces on the block is the resultant of a horizontal and a vertical strength with a ratio of 0.48 in the first series of test and about 0.58 in the second series. The angle of the resultant force is 25.8 ° in the first and of 30 ° in the second. The global configuration of the experimental bench is shown in Figure 1.

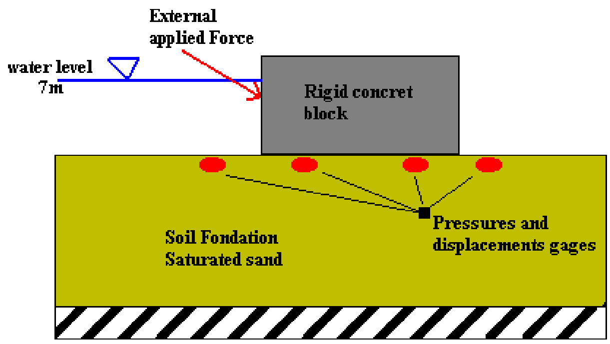


Fig. 1 Experimental bench (Heins and Leeuw, [1])

III. Numerical Model

The proposed numerical model was developed on the basis of the dimensions, the geometry and the loading conditions corresponding to the experimental physical model. The modelling parameters were directly derived from the experiment work. The development of the numerical models and the computations of the model displacement was done using the Plaxis package (version 8.2) [2]. Figure 2 shows the overall geometry configuration of the numerical model, together with the limits conditions. The geometry of the model extends 100m horizontally and 50m vertically, these limits were supposed to be sufficient to avoid disturbances.

For the development of the finite elements model, plain strain conditions were assumed, 15 nodes triangular finite elements were selected for the modelling of the structure and the soil cluster. Figure 3 presents a typical finite element model.

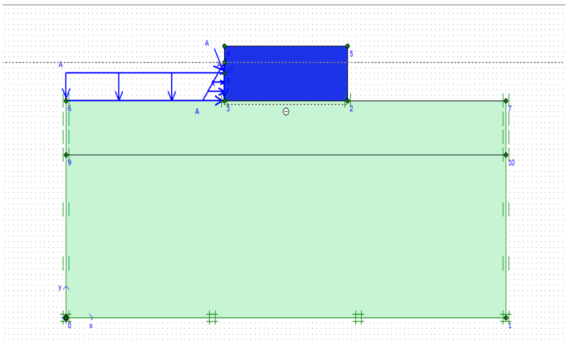


Fig. 2 Geometry of the numerical model

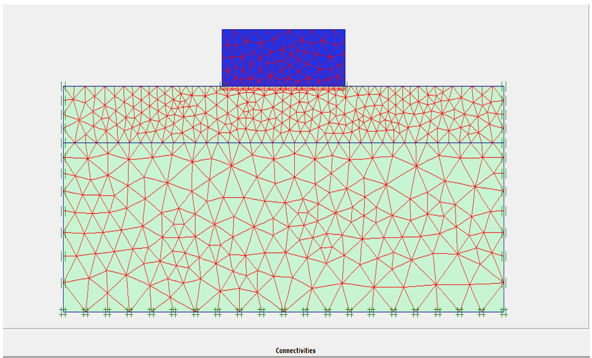


Fig. 3 Typical finite elements model

In the present numerical analysis the behaviour of the soil was represented by the Hardening soil model incorporated into the PLAXIS codes. This behaviour's law is based on the formulation of Duncan and Chang [3] but formulated within the theory of the plasticity. The formulation of this constitutive law incorporates the hardening by shearing and the volumetric hardening, rigidity dependent on strain for the primary load and unloading / loading and the theory of the dilatance of the constraints by Rowe [4]. The parameters of modelling of the soil used in the present analysis are presented in the Table I.

TABLE I
MODELLING PARAMETERS OF THE SOIL

Soil parameters	**Units**	**Soil material**
Type		Drained
γ_{unsat}	[kN/m³]	17.00
γ_{sat}	[kN/m³]	20.00
k_x	[m/day]	1.000
k_y	[m/day]	1.000
E_{50}^{ref}	[kN/m²]	30000.00
E_{oed}^{ref}	[kN/m²]	30000.00
power (m)	[-]	0.50
c_{ref}	[kN/m²]	1.00
φ	[°]	32.00
ψ	[°]	2.00
E_{ur}^{ref}	[kN/m²]	90000.00

The material constituting the structure of the dike is the concrete, and is modelled by the simple elastic law, the behavior of which is defined by the Young modulus and the Poisson's ratio; the values admitted to the modelling are presented in the Table II.

TABLE II
MODELLING PARAMETERS OF THE CONCRETE BLOCK

Parametres	**Units**	**Material: concrete**
Type		Non-porous
γ	[kN/m³]	42.14
E	[kN/m²]	$2.1X10^6$
υ	[-]	0.200

For the computation of the stresses and strains in the model, plastic calculation was selected, with a multiphase's loading using the staged construction procedure of the Plaxis, starting from the loads corresponding to the initial conditions and applying loads gradually. The numerical output gives the relative stresses and strains corresponding to each phase of loading of the numerical model.

IV. RESULTS OF THE NUMERICAL ANALYSIS

The Figure 4 presents the connectivity plot or the deformed model which represents the global deformations and the displacements of the finite elements of the model. At first impression of this result it is clear that the numerical model, under the conditions applied, shows a behaviour that is very comparable to the behaviour of the physical or experimental model.

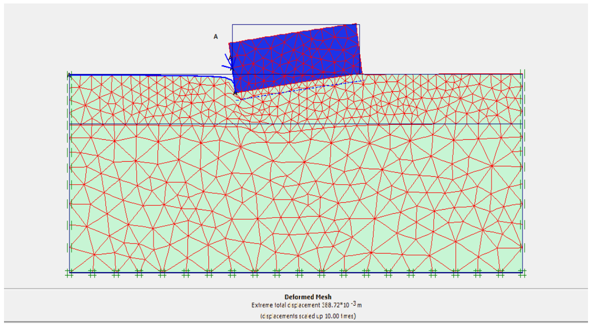


Fig. 4 Connectivity Plot of the model

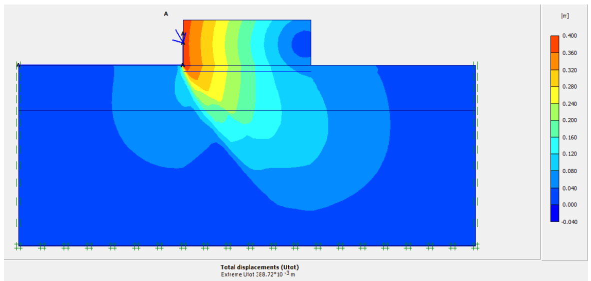


Fig. 5 Total strains computed

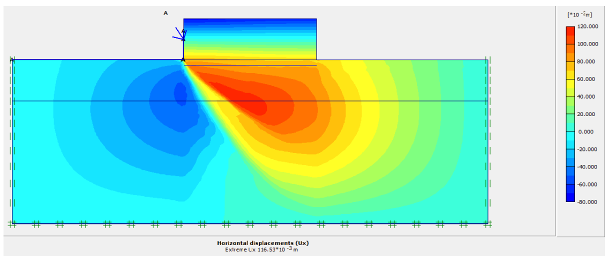


Fig. 6 Horizontal strains computed

Figures 7 and 8 present the diagrams of horizontal and displacements respectively of the dike. As observed experimentally, under the effect of the outside loads applied on the face of the structure, the dike undertake a horizontal movement (figure) 7) which characterizes the sliding, in parallel a rotation is observed by the side of the applied load (figure) 8).

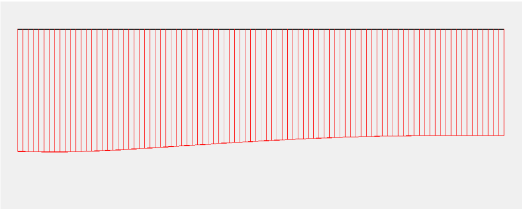


Fig. 7 Horizontal displacements

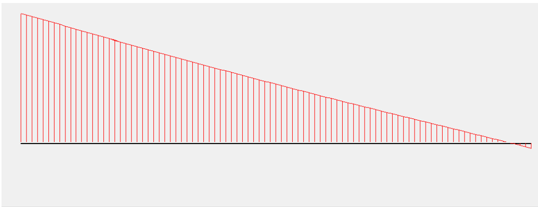


Fig. 8 Vertical strains computed

V. Validation of the Model

The numerical results calculated in the present study will be validated after a direct comparison with the results obtained from the physical models which are supposed to be identical to the reality. This approach is proved to be valid in many previous researches [5].

The predictions of the displacements and the stresses are among the major objectives of the analyses of the interaction between the structure and the soil (Schweiger [6]). The main results out of the present numerical analysis are presented in terms of displacements (horizontal and vertical).

Figures 9 and 10 present an illustration of the confrontation between the experimental and numeric results. For both series of tests; it is very clear that the computed displacements are very comparable to the experimental results, which indicates a satisfactory performance of the proposed numerical model.

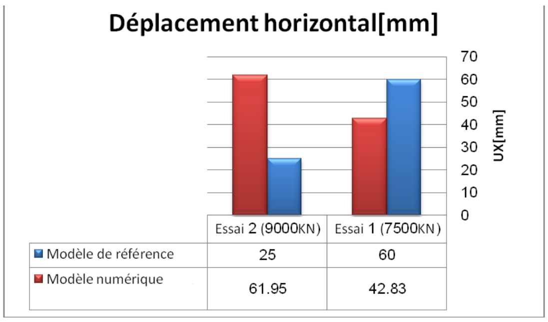


Fig. 9 Horizontal displacement

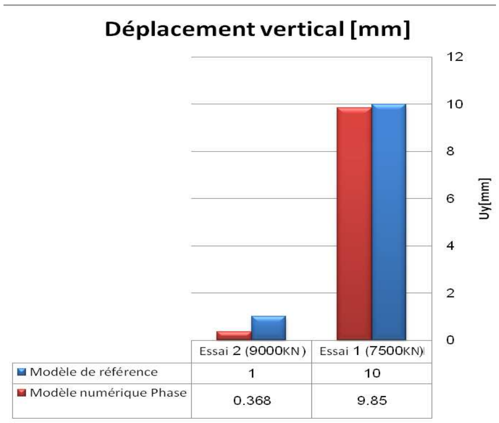


Fig. 10 Vertical displacements

In this section, another model is proposed but this time developed in three dimensions, to compare the results of both simulations with the experimental results. The properties of materials and the parameters of modelling are the same than for the two dimensional model, the limits conditions, loads and drainage conditions, the phasing of the calculation procedures are also identical. Figure 11 shows a typical configuration in 3 dimensions of the numerical model.

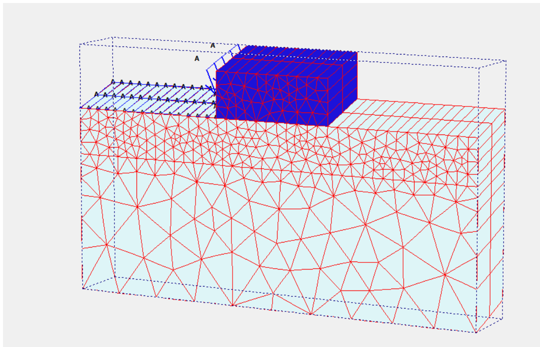


Fig. 11 Typical 3D finite elements model

The total displacements calculated are presented in the Figure 12. The results obtained in terms of horizontal and vertical displacements are also illustrated in the Figure 13. The obtained results indicate a rather reasonable correlation between the numerical simulations and the experimental approach.

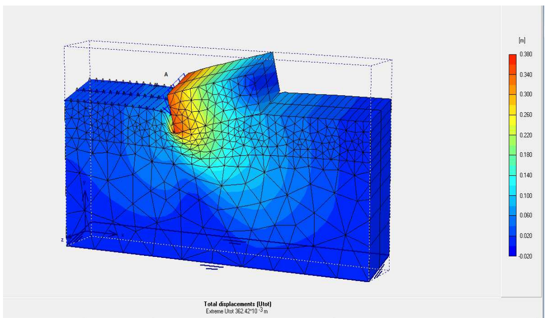
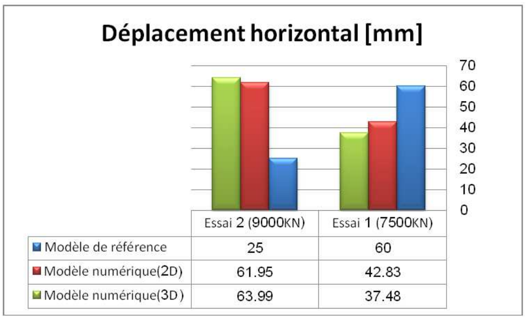


Fig. 12 Total displacements computed by the 3D model



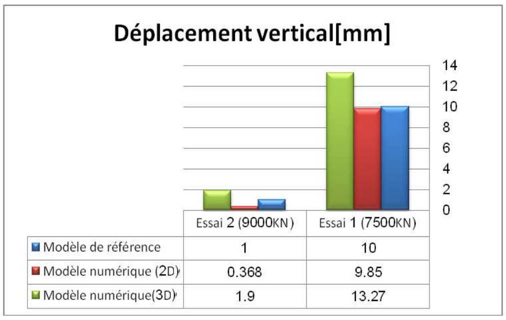


Fig. 13 Horizontal and vertical displacements correlations

Regarding the behaviour of the retaining dike investigated, it could be concluded that the overall displacements are a combination of rotation and sliding. Usual design methodology of this type of geotechnical structures [7] considers the sliding and rotation as separate effects of the behaviour of the dike. Important safety factors are usually imposed for the stability. On the other hand, and as far as the failure of the dike is concerned, the rotation could not constitute a risk for the stability of the structure when subjected to the important external loads applied (from the water front and the side forces applied), however, the sliding of the structure could be a major risk for its safety, as it could affect the overall stability. Uncontrolled horizontal displacements could be a major cause for disorder.

VI. Conclusion

Out of this investigation, it could be concluded that, for the concept of modelling used, the numerical models developed in 2 and three dimensions performed satisfactorily, and could be used as a tool for further parametric investigation on the behaviour and risk assessment of the dikes. Also those observations remain only valid for the geometry and conditions taken from the experimental physical model. By taking into account the geometry, the limits conditions, the loading and drainage conditions, numerical models in 2 and 3 dimensions are developed. The numerical results obtained especially in terms of total displacements and overall behaviour of the structure investigated are proven to be satisfactory. As far as the design methodology of the massif retaining dikes is concerned, it could be argued that the stability of the structure considered is mainly affected by the risk of sliding rather than rotation, and could constitute a major risk for its safety.

Uncontrolled horizontal displacements could be the major cause for disorder of such structures.

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